Chapter 40
Assessing the Potential of Torrefaction for Locally Available Biomass in Mauritius

Surroop Dinesh and Mooloo Devina

Abstract Mauritius is highly dependent on fossil fuel imports for its own energy provision with only a minor contribution of renewable energy sources. Mauritius has however got potentials to increase its renewable energy share through increased biomass use. Conversely, there are several problems associated with biomass which reduces its appeal as a fuel compared to conventional fossil fuels. Pre-treatment technologies can nevertheless help valorise biomass. Torrefaction is known to be a mild pyrolysis process during which the lignocellulosic material in the biomass is decomposed and moisture and volatiles are eliminated. In this paper, the effect of torrefaction on the energy content and the chemical composition of four different locally available biomass feedstocks in Mauritius namely: Elephant grass (Napier grass), cane tops and leaves, wood wastes and palm trunks have been investigated. Samples of the biomass were treated at varying temperatures in the range of 200–300 °C in an inert atmosphere with a residence time of 1–3 h. The optimum residence time and temperature for each of the different biomass feedstock were determined. Enhancement ratios in the energy content of the torrefied biomass varied from 1.01 to 1.42. It was found that 1 kg of torrefied biomass could displace 0.776–0.855 kg of coal and reduce emissions of greenhouse gases from 2.01 to 2.34 kg. It was evaluated that savings of Rs. 3.19, Rs. 3.34, Rs. 3.52 and Rs. 3.29 per kg of torrefied sawdust, elephant grass, and CTL and palm wastes could also be made.

Keywords Torrefaction · Lignocellulosic · Greenhouse gases

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Short Introduction

Mauritius (a small developing island) has no natural fossil fuel reserves, but has however important potentials to increase its renewable energy share through increased biomass use. This study was therefore initiated to assess the potential of torrefaction of biomass in Mauritius. The benefit of torrefaction is that a fuel produced (commonly known as biocoal) has a uniform composition compared to unprocessed biomass. The amount of coal that can possibly be displaced and the greenhouse gases avoided by the use of torrefied biomass in Mauritius was subsequently evaluated.

Introduction

The world is living with growing anxieties of an imminent energy crisis (Chang et al. 2011; Riley 2000). Escalating energy demands in developed and developing countries whilst an almost stagnant energy supply is only aggravating the scenario. The globe's leaders are already insecure about the price and continued supply of fossil fuels in the forthcoming years. In January 2012, it was reported that the price of oil was around $103 per barrel (Kahn 2012). An analysis of the Central Statistics Office (CSO) report leads to the conclusion that Mauritius is heavily dependent on imports to be able to meet its energy demands (CSO 2010). 82.5 % of the primary energy requirement in the island is fulfilled by fossil fuel imports with a 55 % share of petroleum products (CSO 2010). Hence, the country is highly susceptible to energy shocks such as rise in oil price in the world.

Moreover, growing fossil fuel use worldwide is also increasing the amount of greenhouse gas emissions in the world leading to a threatening climate change. Developing countries are considered to be more vulnerable to the climate change problem since they possess little resources to adjust and adapt to climate change in terms of social, technological and financial aspects (UNFCCC 2007). Mauritius, though having little contribution to climate change compared to developed countries is already experiencing its negative effects. Rise in air temperature from 0.74 to 1.2 °C in comparison to the 1990s, rise in sea level by 1.5 mm per year and an 8 % decrease in rainfall as well as warmer summers and milder winters (Mauritius Meteorological Services 2012) are some of the experienced consequences of climate change in the country. To combat the problems related to fossil fuels, alternative energy sources need to be sought. Biomass is a promising alternative to replace fossil fuels given its wide distribution globally compared to other sources of fuel (US DOE 2011). Additionally, biomass is also a clean source of energy and will help in the reduction of emissions of greenhouse gases (Zhang et al. 2010).

However, the contribution of biomass in energy generation in Mauritius is very minimal accounting for only 20.5 % of the electricity generation in the country which is sustained by the biomass bagasse, a by-product of the sugarcane milling process (CSO 2010). It can be clearly deduced that expansion of the biomass sector involves various challenges. Along with political, economic barriers and a lack of strategies and frameworks for promoting the biomass industry, the properties of the biomass itself as a fuel act as a significant hindrance for its own development (Bridgeman et al. 2008).

A comparison of coal with biomass reveals that the latter is still regarded as a relatively inferior fuel not able to meet the same benchmarked characteristics as coal (Bridgeman et al. 2008). One of the main challenges encountered by biomass is that their low calorific value and low ash sintering temperature causes technical problems during its use in combustion and gasification (Baxter et al. 1998). Biomass also have high moisture content and low bulk density which further hinder its use due to high transportation costs associated for handling it (Kumar et al. 2009). A high level of moisture also poses storage difficulties and dangers of degradation or self-heating of the biomass along with reduction in the efficiency of biomass and it limits the gasifier construction design (Bridgeman et al. 2008). Moreover, the heterogeneous nature of biomass hinders its competitiveness in the energy market (Chew and Doshi 2011). Efficient biomass conversion technologies can aid to improve of the problems related to biomass (Rousset et al. 2011).

Torrefaction is a thermal pre-treatment process, which can be described as a mild pyrolysis, during which the biomass is subjected to a temperature range of 200–300 °C under atmospheric conditions with little or no oxygen (Rousset et al. 2011). The process helps to. Torrefaction is advantageous in many ways: biomass degradation is reduced since the water absorption capacity of the torrefied biomass is reduced and alongside, its energy value is also improved on a mass basis; the torrefied biomass can be easily ground to a powder and it can also be co-fired with coal (Arias et al. 2008; Bergman et al. 2005; Rousset et al. 2011). The properties of the torrefied biomass are somewhat similar to low rank coal.

Various studies have been conducted on torrefaction (Arias et al. 2008; Bridgeman et al. 2008; Patel et al. 2011; Rousset et al. 2011; Uemura et al. 2010) but none of them have focused on agricultural wastes: cane tops and leaves and palm trunks as well as the energy crop elephant grass. This paper investigates the relationship between the calorific value and the residence time and torrefaction temperature of four different biomass species available in Mauritius (2012) (sawdust, elephant grass, cane tops and leaves and palm trunks) and attempts to find the optimum temperature for each biomass.

Methodology

Moisture Content and Dry Mass Determination

To find the moisture content of the biomass, 100 g of each of the 5 different samples were weighed in different plates. The samples were then placed in the oven at a temperature of 105 °C and allowed to dry until constant weight was obtained.

Energy Content of Biomass

The energy content of the biomass samples was evaluated on a dry basis using a bomb calorimeter model 3188 series. The sample was first dried in an oven (Labcon) at a temperature of 105 °C for a period of 3 h. It was then pelletised. The pellet should weigh less than 1 g. The sample was placed in a metal capsule which is then positioned on a ring which acted as an electrode to which a bent fuse wire is attached such that it touches the sample. The ring was placed on the bomb cylinder which is afterwards filled with oxygen at a pressure of 25 atm. The bomb cylinder was then connected to ignition wires and lowered in the bomb calorimeter bucket filled with 2 l of water. After mounting the stirrer on the calorimeter bucket, mixing was allowed in the vessel. The initial temperature of the water was next recorded before switching on power to fire the fuse wire. The final temperature reached was noted and the higher heating value of the biomass was calculated taking into consideration the temperature difference and mass of the sample.

Torrefaction Experiment

A batch cylindrical reactor with a length of 10 cm and a diameter of 10 was used. The reactor was enclosed in a heater whose temperature can be varied from 0 to 300 °C is used. The reactor had a gas inlet for supplying nitrogen to the reactor and a gas outlet to allow flue gas to leave the reactor. Nitrogen was supplied to the reactor at a rate of 2 litres per minute. For each run, 5 g of sample was placed in the reactor for a period of 1 h at the required temperature. The heater was then switched off. The sample was allowed to cool in the reactor to room temperature before being removed after which the torrefied sample was weighed. Four different temperatures were chosen for the study: 230, 250, 270, 290 °C. The torrefied samples were then analysed for their composition and heat value using a bomb calorimeter.

Results and Discussion

Mass Loss at Different Torrefaction Temperatures and Residence Time

One of the main benefits of the torrefaction process is that it eventually leads to the complete drying of the biomass and torrefied biomass is also known to be less prone to moisture absorption (Patel et al. 2011). Hydrophobicity is conferred to the biomass due to the breaking of its OH bonds during the torrefaction process and its inability for hydrogen bonding (Bergman et al. 2005). Following torrefaction, char and volatiles are obtained as end-products. It has been reported that mass loss gives an indication of the impact of torrefaction on a particular biomass (Almeida et al. 2010). The mass loss occurring can be mainly attributed to the degradation of the hemicellulose structure producing volatiles (Almeida et al. 2010; Patel et al. 2011). Chen and Kuo (2011) observed that at a temperature of 260 °C 37.98 wt% of hemicellulose were degraded while at 290 °C 58.33 wt% of hemicellulose were decomposed. Temperature and residence time significantly affects the torrefaction process (Bergman et al. 2005).

Figures 40.1, 40.2, 40.3 and 40.4 demonstrate the relationship between mass loss, torrefaction temperatures and residence times of CTL, Elephant grass, Palm wastes and sawdust respectively. As the temperature and residence time was increased, a rise in mass loss was experienced. From Fig. 40.1, it was observed that for a residence time of 1 h, as the temperature increased from 230 °C to 290 °C, the mass loss in CTL also increased from 71.1 to 83.4 %; at 2 h residence time, the mass loss varied from 74.9 to 86.0 % while at 3 h residence time, variations in mass loss from 76.2 to 89.1 % were observed. Similarly, in Fig. 40.2, as the temperature rose from 230 to 290 °C for a residence time of 1 h, noticeable mass losses were observed in the elephant grass species ranging from 85.3 to 92.0 %. The rise in residence time from 1 to 3 h at temperatures of 200 °C, 230 °C, 250 °C and 290 °C brought about increases in the mass loss from 85.3 to 85.9 %, 86.6 to 89.6 %, 91.2 to 92.3 % and 92.0 to 93.1 % respectively. Likewise, in Fig. 40.3, a variation in temperature from 230 to 290 °C for 1 h caused an increase in the mass loss of the palm wastes from 53.0 to 81.2 %. At 230 °C, an elevation in residence time from 1 to 3 h caused mass losses to increase from 53.6 to 54.8 %. From Fig. 40.4, it was observed that at a residence time of 1 h, as the temperature augmented from 230 to 290 °C, the mass loss in the sawdust increased

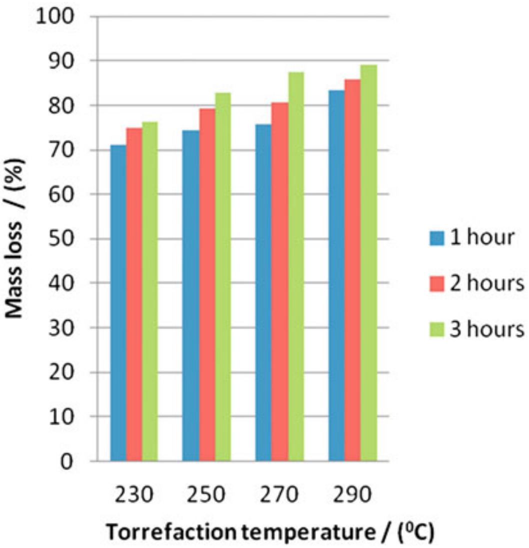


Fig. 40.1 Mass loss of CTL at different torrefaction temperature and residence time

Fig. 40.2 Mass loss of elephant grass at different torrefaction temperature and residence time

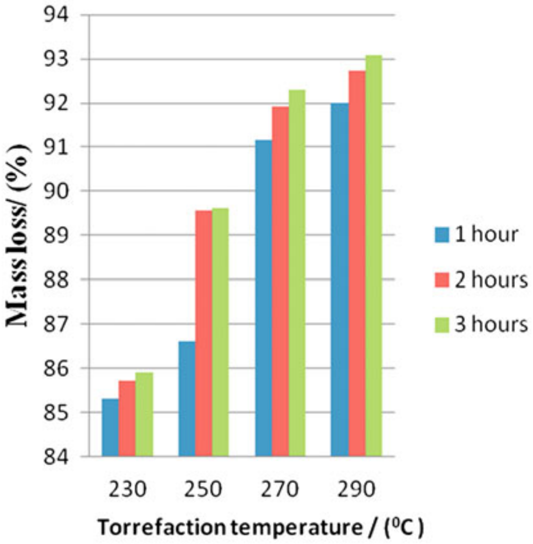
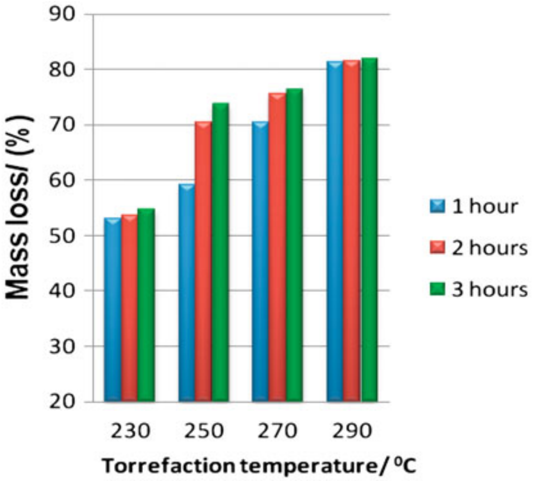


Fig. 40.3 Mass loss of palm wastes at different torrefaction temperature and residence time



from 16.5 to 37.6 %. For residence times of 1, 2 and 3 h, the mass loss are as follows: at 230 °C, 16.5, 25.9, 30.7 %; at 250 °C, 40.4, 41.7 and 44.2 %; at 270 °C, 55, 60 and 64.3 %; at 290 °C, 67.6, 68.5 and 71.4 %.

A rise in temperature and residence time brings about a decrease in the solid bio-coal yielddue to decomposition of the lignocellulosic structures in the biomass producing more volatiles (Medic et al. 2012). Similar trends for mass loss at different torrefaction conditions for oven dried E. grandis, E. saligna, C. citrioda samples were observed (Almeida et al. 2010).

During the torrefaction process, drying of biomass occurs at temperatures of 100–150 °C (Patel et al. 2011). From experiments, it was determined that when the

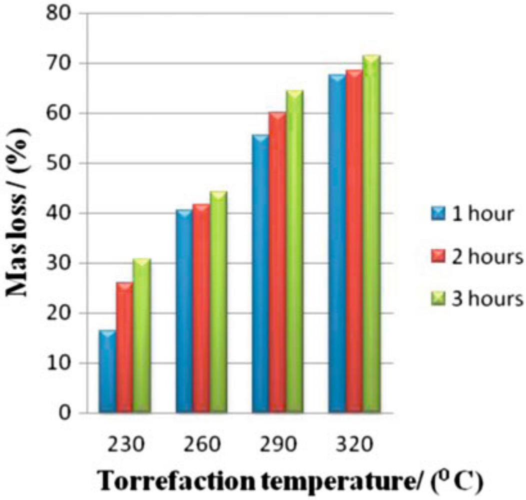


Fig. 40.4 Mass loss of sawdust at different torrefaction temperature and residence time

different biomass CTL, palm wastes, elephant grass and sawdust were dried at a temperature of 105 °C, the mass loss due to moisture was 63.53, 52.89, 84.44 and 14.80 % respectively. Further increase in temperature from 150 to 200 °C caused depolymerisation and degradration of the shortened polymer structure within the solid structure of the biomass (Patel et al. 2011). At temperatures greater than 200 °C, the biomass started to decompose liberating volatiles and leaving behind a solid product known as char (Bergman et al. 2005). Thermal decomposition of the chemical compounds present in biomass such as hemicelluloses and celluloses cause mass losses and since hemicelluloses is less thermally, it is more easily degraded (Almeida et al. 2010). Rising temperatures lead to a decrease in solid bio-char yield (Zhang et al. 2010). The loss in mass was greater at temperatures higher than 250 °C. This may be attributed to the higher reactivity of hemicellulose at temperatures greater than 250 °C (Medic et al. 2012).

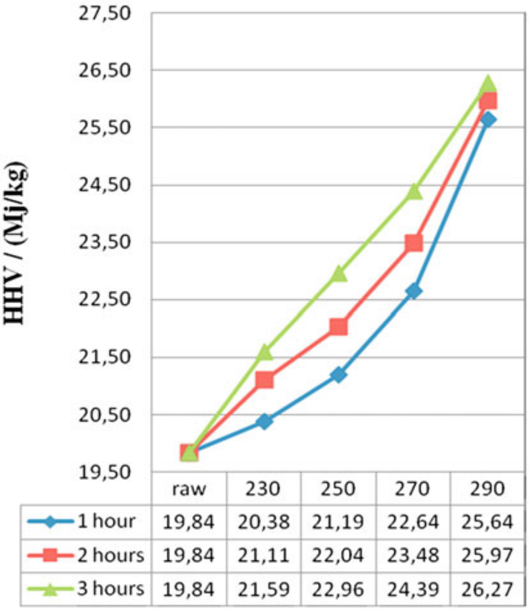
From Figs. 40.1, 40.2, 40.3 and 40.4 it can be deduced that the mass losses for the different biomass are dissimilar. The mass loss was caused mainly by the moisture loss and devolatisation in the biomass. A rise in temperature gives rise to a decrease in the mass yield, oxygen content and volatiles but an increase in the carbon content (Yan et al. 2009). At a temperature of 230 °C and residence time of 1 h, elephant grass has the highest mass loss of 85.3 % followed by CTL with a mass loss of 71.03 % and palm wastes with a mass loss of 53.0 %. From Table 40.1, it can be deduced that elephant grass has higher moisture content than CTL whose moisture content is higher than that of palm wastes (52.89 %). Since the raw material used for the torrefaction experiments were on a wet basis, this explains that the moisture content of the samples influence the percentage mass. Another factor responsible for the difference in the mass of the 4 different biomass is the lignocellulosic content which varies for the different biomass.

Calorific Value at Different Torrefaction Temperature and Residence Time

The calorific value relates to the energy released during the burning of fuel in the presence of air. The gross calorific value represents the maximum amount of energy recoverable from the biomass. A rise in the calorific value indicates an improvement in the energy content of the torrefied biomass compared to the raw biomass (Almeida et al. 2010). One of the major challenges faced by biomass for its potential use as a fuel is its low calorific value. The torrefaction process helps to enhance the energy content of the fuel.

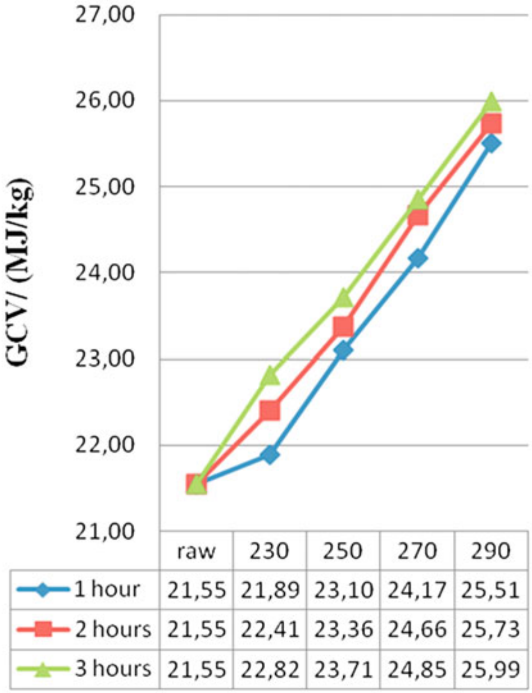
The relationship between the calorific value, torrefaction temperature and residence time for CTL, palm wastes, elephant grass and sawdust is depicted in Figs. 40.5, 40.6, 40.7, 40.8 respectively. Improvements in the energy content of: CTL from 21.89 MJ/kg to 25.51 MJ/kg; Palm wastes from 20.38 to 25.64 MJ/kg; elephant grass from 20.66 to 21.91 MJ/kg; sawdust from 20.79 to 26.82 MJ/kg have been observed as torrefaction temperature was increased from 230 °C to 290 °C for a residence time of 1 h. The heating value of the biomass was observed to increase with the torrefaction temperature. This can be explained by the decrease in the oxygen to carbon ratio which is caused by the degradation of the lignocellulosic material in the palm wastes (Li et al. 2012). Additionally, an increase in residence time also improved the calorific values of CTL, palm wastes,

Fig. 40.5 GCV change in CTL at torrefaction temperature and residence time



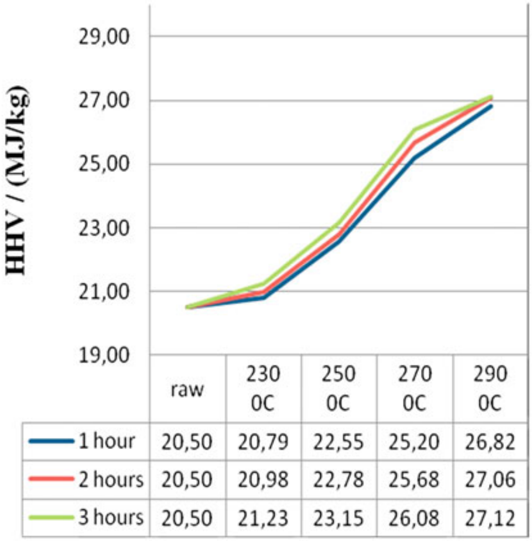
	raw	230	250	270	290
1 hour	19,84	20,38	21,19	22,64	25,64
2 hours	19,84	21,11	22,04	23,48	25,97
3 hours	19,84	21,59	22,96	24,39	26,27

Fig. 40.6 GCV variation in palm waste sat torrefaction temperature and residence time



	raw	230	250	270	290
1 hour	21,55	21,89	23,10	24,17	25,51
2 hours	21,55	22,41	23,36	24,66	25,73
3 hours	21,55	22,82	23,71	24,85	25,99

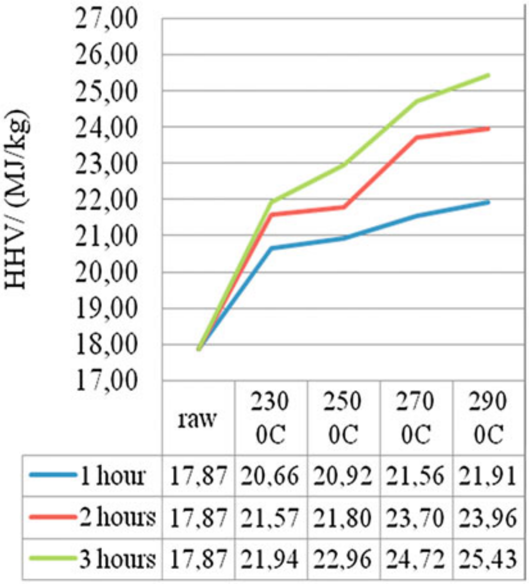
Fig. 40.7 Energy changes in elephant grass at different torrefaction temperature and residence time



	raw	230 0C	250 0C	270 0C	290 0C
1 hour	20,50	20,79	22,55	25,20	26,82
2 hours	20,50	20,98	22,78	25,68	27,06
3 hours	20,50	21,23	23,15	26,08	27,12

elephant grass and sawdust. Changes in the calorific value at a temperature of 270 °C and for an increase in residence time from 1 to 3 h were noted as follows: CTL, 24.17 to 24.85 MJ/kg; palm wastes, 22.64 to 24.39 MJ/kg; Elephant grass, 21.56 to 24.72 MJ/kg; sawdust, 25.20 to 26.08 MJ/kg.

Fig. 40.8 Energy changes in sawdust at different torrefaction temperature and residence time



	raw	230 0C	250 0C	270 0C	290 0C
1 hour	17,87	20,66	20,92	21,56	21,91
2 hours	17,87	21,57	21,80	23,70	23,96
3 hours	17,87	21,94	22,96	24,72	25,43

Similar trends have been obtained with different biomass such as *E.Saligna* and *E.grandis* and *C.citriodora* (Almeida et al. 2010). The increase in calorific value with rise in temperature at specific residence time can be explained by the fact that during torrefaction, carbon monoxide and carbon dioxide are formed due to carboxylation reactions and splitting of the acetyl group present in the xylan chain in the biomass (Ponder and Richards 1991; Shen et al. 2010). The carbon dioxide formed reacts with the char formed during the thermal degradation of the sawdusts producing more carbon monoxide (Li et al. 2012). The carbon dioxide and carbon monoxide thus liberated causes removal of oxygen from the solid char thus decreasing the oxygen to carbon ratio in the torrefied sawdust and leaving behind a higher calorific value solid char (Li et al. 2012). As the torrefaction temperature and residence time is increased, an increase in fixed carbon and a decrease in volatiles and oxygen contentwerenoted for different varieties of biomass thus increasing its suitability for energy production (Almeida et al. 2010; Kongkeaw and Patumsawad 2011). During fuel combustion, the carbon in the fuel is mainly responsible for the exothermic reaction occurring while the oxygen present has an endothermic role and a higher torrefaction temperature leadsto a higher Carbon and lower Oxygen content (Chen et al. 2011).

Experimentation performed on Wheat straw revealed that at torrefaction temperatures of 230, 250, 270 and 290 °C and residence time of 30 min, the heating value of the torrefied biomass were 19400, 19800 and 22600 kJ/kg (Bridgeman et al. 2008). Likewise, the calorific values of willow at 230, 250, 270 and 290 °C at a residence time of 30 min were determined to be 20,200, 20,600, 21,400 and 21,900 kJ/kg respectively (Bridgeman et al., 2008). Torrefying Reed canary grass at 250, 270 and 290 °C for a period of 30 min resulted in heating values of 20,000 kJ/kg, 20,800 kJ/kg and 21,800 kJ/kg respectively (Bridgeman et al. 2008).

Chen et al. (2011) reported values of: 23.62 MJ to 28.08 MJ/kg for bamboo torrefaction; 23.71 MJ/kg to 29.64 MJ/kg for willow torrefaction at a 1 h residence time. Untreated pine and pine torrefied at 230, 260 and 280 °C had the following energy values: 20.2, 20.37, 20.45 and 21.70 MJ/kg respectively (Pierre et al. 2011). However in another study, heating values of 18.46, 22.87, 25.77 and 28.00 MJ/kg for untreated Banyan and Banyan samples torrefied for 1 h at temperatures of 230, 260 and 290 °C were reported (Chen et al. 2011). The difference in HHV can be explained by the difference in lignocellulosic content of the different biomass.

At temperatures of 220, 250 and 300 °C, calorific values of torrefied Mesocarp fibres were reported as 19.03, 19.24 and 22.17 MJ/kg respectively (Uemura et al. 2010) which are than lower those reported in Fig. 40.6. This can be attributed to the difference in biomass species, physical properties of the biomass and its harvesting season. The palm species used in the current study is utilised for the production of palm hearts in Mauritius which is used for culinary purposes and exportation while that used in Uemera et al. (2010) is a species grown in Malaysia specifically for oil production. Furthermore, the palm wastes consisted of only trunks and fronds which had a higher woody content than the mesocarp fibre and kernel shell. Moreover, the heating value of the raw palm biomass had been determined on a dry basis and was found to be 19.84 MJ/kg. In contrast, in a study performed on palm wastes, heating values of 18.8 MJ/kg and 20.1 MJ/kg for mesocarp fibre and kernel shell were reported respectively (Uemura et al. 2010).

The enhancement in calorific value was calculated by taking the ratio of the gross calorific value at the specified temperature and time to that of the of the raw biomass sample. From the Table 40.1, enhancement ratios in the energy content of the torrefied biomass were found to vary from 1.02 to 1.34 depending on the

Table 40.1 Enhancement in HHV of the different biomass at different conditions

Enhancement in HHV		Torrefaction residence time		
Biomass	Torrefaction temperature (°C)	1 h	2 h	3 h
CTL	230	1.02	1.04	1.06
	250	1.07	1.08	1.10
	270	1.12	1.14	1.15
	290	1.18	1.19	1.21
Elephant grass	230	1.16	1.21	1.23
	250	1.17	1.22	1.29
	270	1.21	1.33	1.38
	290	1.23	1.34	1.42
Palm wastes	230	1.03	1.06	1.09
	250	1.07	1.11	1.16
	270	1.14	1.18	1.23
	290	1.29	1.31	1.32
Sawdust	230	1.01	1.02	1.04
	250	1.10	1.11	1.13
	270	1.23	1.25	1.27
	290	1.31	1.32	1.32

torrefaction temperature and the residence time of the biomass. It was observed that as the torrefaction temperature was increased, the enhancement ratio increased accordingly due to an increase in the energy in the pre-treated biomass. Likewise, with increases in residence time, the energy enhancements were also observed. At a temperature of 290 °C and following 1 h of torrefaction, the enhancement of HHV for CTL was determined to be 1.18. In the case of palm wastes, at a temperature of 230 °C, for residence times of 1, 2 and 3 h, the GCV enhancement increased from 1.03 to 1.06 to 1.09 respectively. When the torrefaction temperature is increased from 230 °C to 290 °C for a residence time of 1 h, the enhancement is however more significant. This is because at lower temperatures the hemicellulose content is degraded but temperatures higher than 250 °C initiates degradation of the cellulose and lignin content as well (Chen et al. 2011). Enhancement ratios in the energy content of the torrefied elephant grass were found to vary from 1.16 to 1.42 depending on the torrefaction temperature and the residence time of the biomass. At a temperature 290 °C and following 1 h of torrefaction, the enhancement of HHV was determined to be 1.23. However, Chen et al. (2011) reported values of 1.40, 1.32 and 1.46 respectively for the same conditions with the biomass bamboo, banyan and willow. The lower value recorded can be attributed to the lignocellulosic content of the biomass owing to the fact that the elephant grass was harvested after 10 months and was not a fully mature plant.

Energy to Mass Loss Characteristics

The Energy gain/mass loss for the four different biomass under study (Sawdust, Elephant grass, CTL and palm wastes) were evaluated at different torrefaction temperatures and residence time. From Table 40.2, it was observed that the highest energy gain to mass loss ratio for sawdust was obtained at torrefaction conditions of: 230 °C, 3 h followed by 230 °C, 2 h; 250 °C, 2 h; 250 °C, 3 h and 270 °C, 3 h. In the case of Elephant grass, the utmost energy gain/mass loss can be specified at the following condition: 290 °C, 1 h; 270 °C, 1 h and 290 °C 2 h. For CTL, the greatest energy gain to mass loss are at 250 °C, 1 h; 230 °C 1 h; and 230 °C, 2 h. As for palm wastes, the highest mass loss to energy loss are obtained at the following conditions: 250 °C, 1 h, 230 °C, 3 h; 250 °C 2 h; 230 °C, 1 h.

In this study, the energy gain to mass loss ratio was used as an indicator for the determination of the optimum torrefaction conditions for the different biomass with the highest ratio representing the best condition. A high energy gain to mass loss ratio would mean that energy recovered in the char is higher than the mass loss in the volatiles which also contain energy. The optimal condition conditions are summarised in Table 40.3. In the case of palm wastes, both a temperature of 250 °C 2 h and 230 °C 3 h gave the same mass to energy ratio. However the torrefaction condition with a lower residence time was chosen since a higher residence time would increase the energy requirement of the process. It is observed that optimum conditions obtained for each biomass is different.

Table 40.2 Energy gain versus mass loss of different biomass at different torrefaction conditions

Energy gain/mass loss					
Residence time	Torrefaction temperature (°C)	Sawdust	Elephant grass	CTL	Palm wastes
1 h	230	6.39	−26.40	27.73	22.72
	250	15.72	−0.49	32.35	26.88
	270	15.37	13.05	14.63	16.44
	290	17.42	13.60	17.91	18.24
2 h	230	20.50	−21.94	19.97	21.55
	250	19.86	9.92	18.35	19.16
	270	18.68	11.58	17.35	18.04
	290	17.74	12.56	18.92	18.94
3 h	230	20.50	−20.04	17.73	19.17
	250	19.59	7.73	19.37	19.63
	270	18.86	11.20	19.99	19.81
	290	17.88	11.86	19.93	19.65

GHG Avoided

The torrefied biomass can be potentially co-fired with coal in existing power plants thus displacing a significant quantity of coal. The amount of coal displaced and greenhouse gas avoided by the different biomass torrefied at their optimum torrefaction conditions are shown in Table 40.4.

From Table 40.4, it can be observed that burning 1 kg of sawdust torrefied at 2 h at a temperature of 230 °C will avoid 19.56.4 g CO_2 by displacing 0.776 kg of coal. Amongst the different biomass, the GHG emissions avoided by torrefied CTL is highest due to its higher energy content and hence ability to displace a relatively larger amount of carbon. It can be inferred that burning torrefied biomass will help offset the use of coal and will considerably reduce greenhouse gas emissions.

Table 40.3 Optimum conditions for torrefaction of each of the different biomass

Biomass	Torrefaction temperature (°C)	Residence time/(h)	GCV/(MJ/kg)
Saw dust	230	2	20.98
Elephant grass	290	1	21.91
CTL	250	1	23.10
Palm wastes	250	1	21.19

Table 40.4 Amount of coal displaced per kg of torrefied biomass

Biomass	Torrefaction temperature (°C)	Residence time/(h)	Amount of coal displaced per kg biomass/kg	Electrical energy from coal displaced/kWh_e	GHG avoided/ (g CO_2)
Saw dust	230	2	0.776	1.34	1956.4
Elephant grass	290	1	0.811	1.47	2146.2
CTL	250	1	0.855	1.63	2379.8
Palm wastes	250	1	0.785	1.37	2000.2

Conclusion

Pre-treatment technologies can however help valorise biomass as a source of fuel. Torrefaction of four diverse biomass available in Mauritius (2012) involving elephant grass, cane tops and leaves, palm trunk wastes and sawdust have been considered in this study. The biomass were subjected to different temperatures (ranging from 230 to 290 °C) and residence times (1–3 h). During the process, major changes in mass loss were reported as the torrefaction temperature and residence time was increased. The mass loss was however varied for the different biomass depending on their composition. Likewise, a rise in temperature and residence time also brought about improvements in the energy content of the fuel. However, mass loss can also be associated with a loss in energy since the volatiles given off contain significant amount of energy. Thus, in certain cases, energy changes due to mass loss overpowered the energy gain due to torrefaction. Hence a ratio of energy gain to mass loss was calculated and the conditions giving the highest ratio were considered as the optimum torrefaction conditions for the different biomass studied and were as follows: CTL, 250 °C, 1 h; elephant grass, 290 °C, 1 h; sawdust, 230 °C, 2 h and palm wastes, 250 °C, 1 h. An evaluation of the amount of coal displaced and subsequently the amount of greenhouse gas avoided by the use of torrefied biomass was conducted.

The result and discussion from this study will be helpful for those willing to use torrefied CTL, palm wastes, wood wastes and elephant grass as a source of solid fuel. The potential use of biocoal produced from biomass through the torrefaction process is very solicited in Europe and the technology is under research and development in various countries. Torrefaction products can be projected as being a clean source of energy capable of offsetting large amounts of coal and promoting the use of biomass as a fuel. Moreover, due to its reduced carbon dioxide emission, torrefaction projects can be considered for emission reductions via the Clean Development Mechanism.

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